



# THE VALUE OF BIOMEDICAL SIMULATION ENVIRONMENTS TO FUTURE HUMAN SPACE FLIGHT MISSIONS

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# Disclosure Information

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*Beth Lewandowski, PhD*



I have no financial relationships to disclose.

I will not discuss off-label use and/or investigational use  
in my presentation.



# Introduction



- Mars and NEO missions will expose astronaut to extended durations of reduced-gravity, isolation and higher radiation
- These new operation conditions pose health risks that are not well understood and perhaps unanticipated
- Advanced computational simulation environments can beneficially augment research to predict, assess and mitigate potential hazards to astronaut health
- The NASA Digital Astronaut Project (DAP), within the NASA Human Research Program, strives to achieve this goal

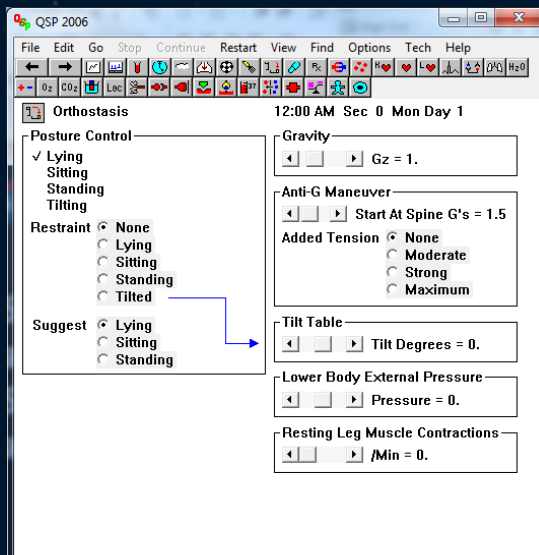


# Quantitative Space Physiology

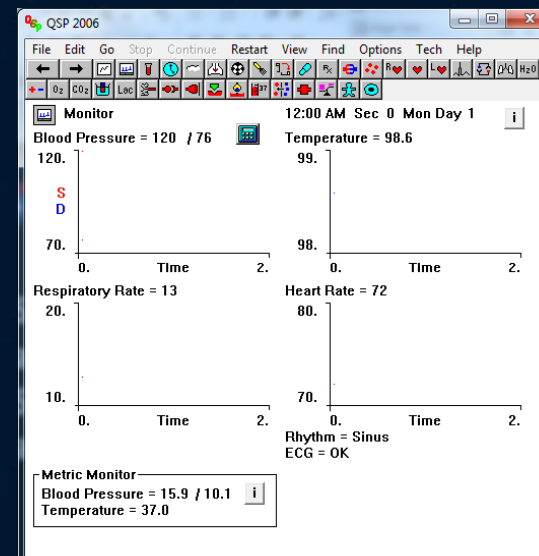


- The University of Mississippi Medical Center's Quantitative Circulatory Physiology education model was adapted for space flight physiology
- The Guyton-Coleman model was substantially expanded to include 4000 variables and equations
- The focus was on physiologic impacts of reduced gravity, analogue environments and nutrition on the cardiovascular system

## Orthostasis and Bed rest controls



## Monitor for basic vitals





# Quantitative Space Physiology Applications



- Predictive simulations for the effect of spaceflight and bed rest on the cardiovascular system
  - Changes in left ventricle mass from preflight to landing day to the third day of the post-flight recovery period of shuttle missions (Summers *et al.*, 2007)
  - Role for lower extremity interstitial fluid volume changes in the development of orthostasis after simulated microgravity (Platts *et al.*, 2007)
  - Mechanisms of cardiac diastolic function changes after microgravity exposure (Summers *et al.*, 2008)





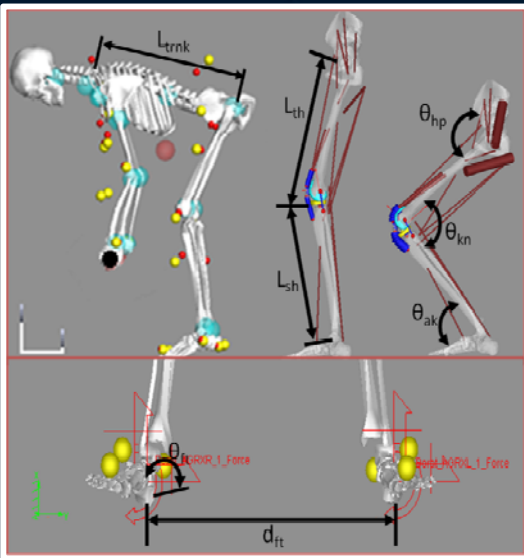
# New Initiatives of the DAP

- Musculoskeletal modeling to augment ongoing research within the Exercise Physiology and Countermeasures (ExPC) Project, to address muscle and bone risks and gaps:
  - “RISK OF IMPAIRED PERFORMANCE DUE TO REDUCED MUSCLE MASS, STRENGTH AND ENDURANCE”
    - **SM7:** Can an integrated post-flight functional task performance test be used on returning ISS crew members to obtain performance decrements?
    - **M7:** Can the current in-flight performance be maintained with reduced exercise volume?
    - **M8:** What is the minimum exercise regimen needed to maintain fitness levels for tasks
    - **M9:** What is the minimum set of exercise hardware needed to maintain those (M8) fitness levels?
  - “RISK OF BONE FRACTURE”
  - “RISK OF EARLY ONSET OSTEOPOROSIS DUE TO SPACEFLIGHT”
    - **B1:** a) Is there an increased lifetime risk of fragility fractures/osteoporosis in astronauts?  
b) Is bone strength completely recovered post-flight, and does BMD reflect it?  
c) What are the risk factors for poor recovery of BMD/bone strength?
    - **B15:** What exercise protocols are necessary to maintain skeletal health and can exercise hardware be designed to provide these?
    - **B30:** What are the loads applied to bone in-flight and during EVA activities and do they increase fracture risk in light of expected bone loss?

*HRP-47065 REV B: HRP Integrated Research Plan (pp. 284-291; 412-436; 455-488) - <http://humanresearch.jsc.nasa.gov>*

## Johnson Space Center

Project & Science Management  
Model Development  
(Physiology)  
Application to Research



**Musculoskeletal Models**

## DAP Musculoskeletal Model

Development & Implementation



## Output



Effect on Muscle,  
Bone and Joints

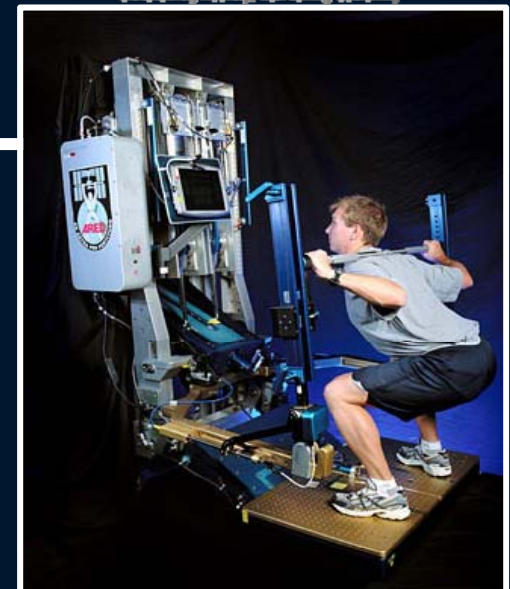


Task Optimization w.r.t.  
Physiological Limits



## Glenn Research Center

Computation Model  
Development for ARED/VIS



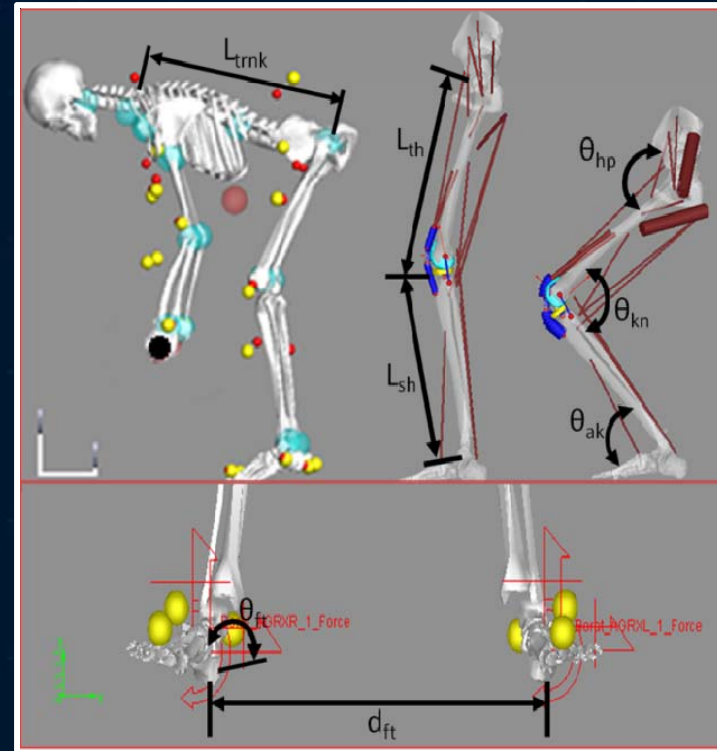
**ARED/VIS Device Model**



# Biomechanical Models



- Human exercise/movement simulation in micro-gravity
  - Squat (regular and single-leg)
  - Dead-lift
  - Heel-raise
  - Hip ab/adduction
  - Hip flexion & extension
- Prediction of:
  - Muscle forces
  - Ground reaction forces
  - Joint torque
  - Mechanical load bones/joints
- Influence of:
  - Anthropometric variation
  - Stance variation
  - Range of motion
- Being developed by the Exercise Physiology Laboratory at Johnson Space Center and University of Washington



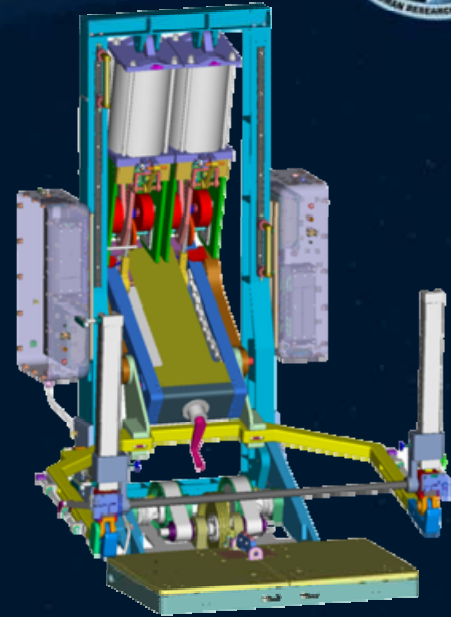




# Advanced Resistive Exercise Device Model



- ADAMS kinematic model of Advanced Resistive Exercise Device and Vibration Isolation System
  - Bar exercises
  - Cable exercises
- Model being developed by ZIN Technologies in Cleveland, OH



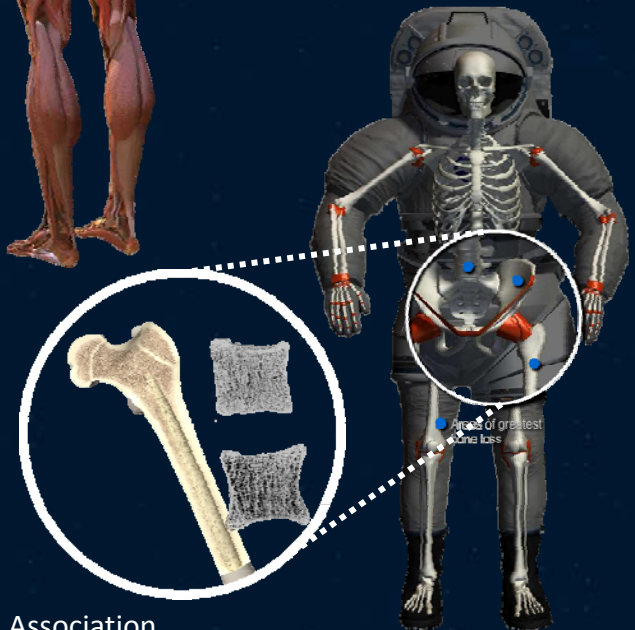


# Muscle and Bone Adaptation Models



- Biomechanical models of exercise countermeasures
- Predicted muscle force is an input to the bone adaptation model
- Models being developed at Glenn Research Center
- Muscle adaptation factors:
  - Neuromuscular drive and activation
  - Muscle atrophy and fiber morphology
  - Blood flow and intramuscular pressure
  - Metabolic processes
  - Fatigue
- Bone adaptation model factors :
  - Cortical bone tissue rate of change
  - Bone fluid calcium rate of change
  - Biochemical equations
  - Mechanical stimulus
  - Cellular dynamics
- Bone adaptation model predicts osteogenesis

*(Pennline, 2009; Lewandowski et al., 2011)*





# End Goal of DAP Musculoskeletal Modeling Effort

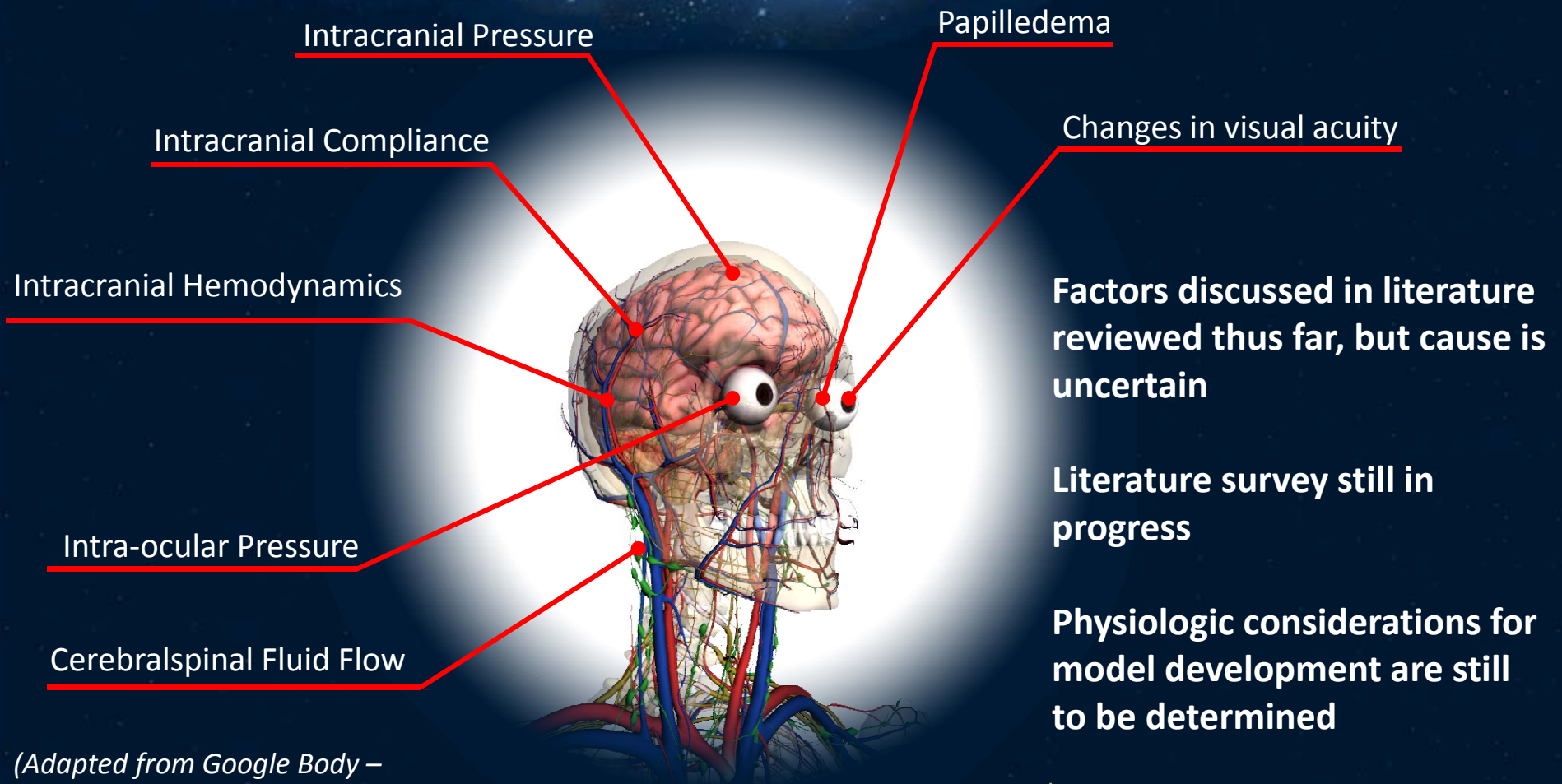


- Load distribution analysis during various exercises
- Customize exercise prescriptions based on individual anthropometrics and needs
- Functional task analysis
- New exercise development (e.g. non-traditional exercise)
- Foundation for advanced exercise device modeling for solar system and planetary surface missions





# Future Work: Risk of Impaired Vision



**Factors discussed in literature reviewed thus far, but cause is uncertain**

**Literature survey still in progress**

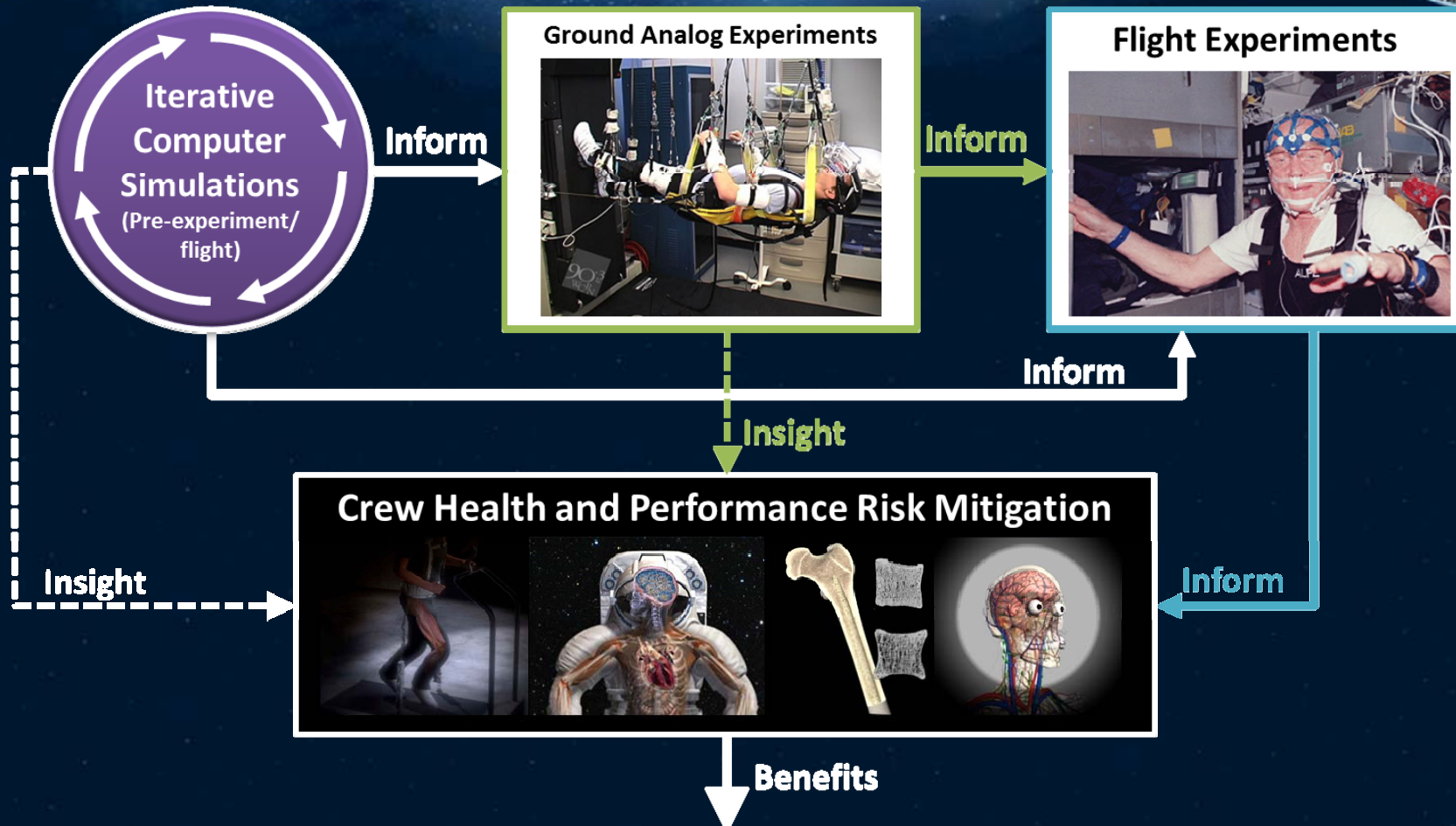
**Physiologic considerations for model development are still to be determined**

*(Adapted from Google Body –  
<http://bodybrowser.googlelabs.com>)*





# The Big Picture



- Improved experiment design
- Reduced cost for ground and flight experiments
- Insight into effects of long duration missions beyond low Earth orbit
- Spin-offs for terrestrial health care applications
- Reduces the need for animal and human subject testing
- Accelerate drug discovery



# Primary References

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# Questions?